Measurements of $\Lambda_c^+$ and $D_s^+$ production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV from STAR

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Motivation: $\Lambda_c^+$

- Significant enhancement in baryon-to-meson ratio observed in central A+A collisions for light hadron and hadrons containing strange quarks
  - Coalescence mechanism well describes the observation
- Enhancement of $\Lambda_c^+/D^0$ ratio depends on the degree of charm quark thermalization and coalescence mechanism implementation

\[ \frac{(p+p)}{(\pi^+ + \pi^-)} \]

\[ \frac{(\Lambda + \bar{\Lambda})}{2K_S} \]

\[ \Lambda_b \]

\[ D^0 \]

\[ \text{Ko: di-quark} \]

\[ \text{Ko: three-quark} \]

\[ \text{SHM} \]

\[ \text{Greco} \]

\[ \text{PYTHIA} \]

STAR arXiv:nucl-ex/0601042

Greco model : S.Ghosh, et. al. PRD 90,054018 (2014)
Motivation: $D_s^+$

- Study hadronization mechanism
  - Strangeness enhancement in A+A collisions
  - $R_{AA}(D_s^+)>R_{AA}(D)$, $D_s^+/D^0$ enhancement due to coalescence hadronization

- More sensitive to properties of Quark Gluon Plasma
  - $v_2(D_s^+)<v_2(D)$ due to earlier freeze-out of $D_s^+$

- Measurements of $\Lambda_c^+$ and $D_s^+$ can help constrain the total charm yield

H. Min et al. PRL 110,112301 (2013)
Heavy Flavor Tracker

- Excellent PID and tracking
- Full azimuthal coverage
- $|\eta|<1$
- HFT in 2014-2016
**$\Lambda_c^+$ and $D_s^+$ reconstruction**

- **Dataset**
  - Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV recorded in 2014
  - About 900M minimum bias events

- **Reconstruction efficiency**
  - Data-driven approach

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<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass ($\text{MeV}/c^2$)</th>
<th>CT</th>
<th>Decay Channel</th>
<th>B. R.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_s^+$</td>
<td>1968</td>
<td>150 $\mu$m</td>
<td>$D_s^+ \rightarrow \phi \pi^+ \rightarrow K^- K^+ \pi^+$</td>
<td>2.32 %</td>
</tr>
<tr>
<td>$\Lambda_c^+$</td>
<td>2286</td>
<td>60 $\mu$m</td>
<td>$\Lambda_c^+ \rightarrow \pi^+ p^+ K^-$</td>
<td>6.35%</td>
</tr>
</tbody>
</table>

*Charge conjugates also measured*
Signal optimization for $\Lambda_c^+$

- Topological cut optimized using TMVA package
- Background extracted from real data using wrong-sign method
- Signal simulated with data-driven fast simulation

![Graphs showing decay length, DCA between daughters, and cosine of pointing angle for kaon, pion, and proton DCA.](image-url)
The first $\Lambda_c^+$ signal observed in heavy-ion collisions!
• Observed an enhancement of $\Lambda^+_c / D^0$ ratio over PYTHIA; similar amplitude to light strange hadrons
  STAR: $1.3 \pm 0.3\text{(stat)} \pm 0.4\text{(sys)}$, PYTHIA: 0.1 - 0.15
• Ko model (0-5%) with coalescence and thermalized charm quarks is consistent with data
$D_s^+$ and $D^+$ reconstruction

- About a factor 4 improvement in $D_s^+$ signal significance compared with the results shown at the QM2015
**D^+ and D_s^+ p_T spectra**

- The $D^+$ $p_T$ spectra from two decay channels are consistent
  - $D^+ \rightarrow \pi^+ \pi^+ K^- \ (B.R. = 9.46\%)$ from Jakub Kvapil (Board ID: I03)
  - $D^+ \rightarrow \phi \pi^+ \rightarrow \pi^+ K^- K^+ \ (B.R. = 0.27\%)$
$D_S^+/D^0$ ratio

- $D_S^+/D^0$ ratio significantly larger than fragmentation baseline
  - ee/ep/pp average: 0.132  
  - M Lisovyi, et. al. EPJ C 76, 397 (2016)
- Comparable enhancement in 0-10% and 10-40%

0-10% data points shifted to the right for clarity
$D_s^+/D^0$ ratio: RHIC vs. LHC

- Comparable ratio between RHIC and LHC in overlapping $p_T$ range

ALICE: JHEP 03, 082(2016)
$D_s^+ / D^0$ ratio: data vs. PYTHIA

- Observed strong enhancement with respect to PYTHIA prediction
$D_s^+/D^0$ ratio : Data vs Model

- Observed strong enhancement with respect to PYTHIA calculation
- Measured ratio is also larger than TAMU model (~10-40%) prediction

- $D_s^+/D^0$ for TAMU: $R_{AA}^{TAMU}(D_s^+)/R_{AA}^{TAMU}(D)\times0.1869$

TAMU: H. Min et al. PRL 110, 112301 (2013)
$D_s^+/D^0$ ratio: charm vs. light quark

- Similar amplitude as light hadron at 3.5-8 GeV/c, but smaller enhancement at 2.5-3.5 GeV/c.
Summary

- First measurement of $\Lambda_c^+$ production in heavy-ion collisions
  - $\Lambda_c^+/D^0 = 1.3 \pm 0.3{\text{(stat)}} \pm 0.4{\text{(sys)}}$, PYTHIA 0.1-0.15
  - Ko model with coalescence hadronization and thermalized charm quarks consistent with our measurement
- Enhancement of $D_s^+/D^0$ ratio with respect to PYTHIA prediction
  - TAMU model underestimates the enhancement in 10-40% centrality
- Observed $\Lambda_c^+/D^0$ (3-6 GeV/c) and $D_s^+/D^0$ (3.5-8 GeV/c) ratios comparable with light hadrons
- Outlook
  - In 2016, STAR collected 2 billion Au+Au events
  - More precise measurements of $\Lambda_c^+ R_{cp}$ and $D_s^+ v_2$ are underway.
Thanks
Compare with QM2015

![Graph comparing D_s/D_0 with p_T (GeV/c) for Au+Au at 200 GeV. The graph shows data points for QM2015 (10-40%) and 10-40% in red, with error bars. The fragmentation baseline is indicated by a yellow line.](image-url)
Strangeness enhancement

\[ \frac{c\bar{s}}{c\bar{u}} \]

\[ \frac{d\bar{s}}{d\bar{u}} \]

\[ \frac{s\bar{s}}{s\bar{u}} \]

Au+Au @ 200 GeV

STAR Preliminary

Long Zhou/USTC